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EDITORIAL

Building green infrastructure to enhance urban resilience to climate change and pandemics

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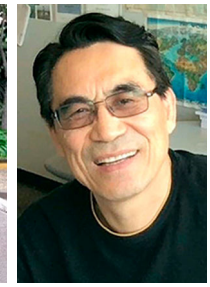

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The looming climate crisis and the ongoing COVID-19 pandemic have highlighted the importance of green infrastructure in and around cities, prompting an urgent call for more functional and sustainable urban planning and design. A number of recent studies have shown that green infrastructure offers a wide range of ecosystem functions and services essential to human wellbeing and urban sustainability (O'Brien et al. 2017; Staddon et al. 2018) which are of particular relevance under climatic and health crises. In this editorial we stress the importance of the existing green infrastructure to withstand climate change-induced stresses, namely those related to increasing climate variability and extreme temperature and precipitation events, and to contribute to human physical and mental health of urban dwellers during lockdown periods. In both cases, green infrastructure plays a major role in providing urban areas with resilience capacity that is key to urban sustainability. We also highlight the need to expand and improve green infrastructure, in particular in regions that are more vulnerable, based on integrative and participatory processes. This editorial was motivated by a webinar organized by the IUFRO (International Union of Forest Research Organizations) Landscape Ecology Working Party (https://iufrole-wp.weebly.com/) held on November 17th, 2020.

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What is green infrastructure?

Green areas of varying sizes (parks, wildlife corridors, urban forests, national parks, etc.) at different scales (e.g., neighborhoods, cities, and urban regions) have different functions in cities and their surroundings. Green infrastructure (GI) refers generally to a system of natural and artificial green spaces that provide ecological and social functions in urban areas. The term was first introduced by Sandström (2002) to expand the purpose of green spaces for recreation to include multiple purposes such as maintenance of biodiversity, city structure, cultural identity, environmental quality, and biological solutions to technical/engineering problems. Tzoulas et al. (2007) further elaborated the GI concept as "all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales". The European Union formally defined GI as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" in rural and urban settings (EC 2013). GI includes not just green and blue (water) spaces, but also other physical features in terrestrial and marine areas such as hedges, agricultural fields, green roofs and walls, eco-bridges, and fish ladders (EC 2013). The United States Environmental Protection Agency (EPA) defined GI as "An adaptable term used to describe an array of products, technologies, and practices that use natural systems—or engineered systems that mimic natural processes—to enhance overall environmental quality and provide utility services" (USEPA 2020). This concept, directed mostly to stormwater runoff management through soil and vegetation based techniques, recognizes, however, multiple environmental and economic benefits, such as air and water purification, energy demand reduction, urban heat islands mitigation, carbon sequestration, aesthetic enhancement, and natural resource benefits.

The green infrastructure concept has been applied mostly to urban settings in an effort to improve city structure and to assure that benefits of natural capital are granted in urban systems dominated by built areas. Urban green (and blue) spaces may support high levels of biodiversity and provide a variety of ecosystem services—including provisioning, regulating, and cultural services—that are crucial to the wellbeing of urban populations, in particular in terms of human health benefits, both physical and psychological (Tzoulas et al. 2007; Felappi et al. 2018; Parker and Zingoni de Baro 2019; Spano et al. 2020). Urban green spaces provide habitats for species and novel ecosystems (Andrade et al. 2020; Teixeira and Fernandes 2020), agricultural connectivity and food security (Yacamán Ochoa et al. 2020), purify air and water, moderate local climate, sequester CO_2, reduce soil erosion, alleviate noise pollution, increase real estate values, improve neighborhood and landscape aesthetics, and enhance human physical and psychological well-being (Bolund and Hunhammar 1999; Wu 2008, 2014; Bratman et al. 2019). In their recent review, Parker and Zingoni de Baro (2019) summarized a comprehensive set of major environmental, economic, social and health and wellbeing benefits. In particular, regulating and cultural services of urban landscapes are increasingly important to human well-being, with accelerating climate change, growing population density, and rising risk of global pandemics. The implementation of GI at different scales may increase urban adaptability to environmental changes and the provisioning of ecosystem services by green spaces (Barker et al. 2019). Moreover, GI contributes to the green economy by playing a crucial role in climate change adaptation and mitigation in urban areas (e.g. enhancing green mobility under the shade of trees) and to circular economy by providing bio-products (e.g. food, compost, timber, bio-plastic, etc.) that can also create job opportunities.

How can green infrastructure increase urban climate resilience?

Urban resilience has been defined as the "ability of an urban system and—all its constituent socio-ecological and socio-technical networks across temporal and

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spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity" (Meerow et al. 2016). Thus, a resilient city is one that anticipates, plans, and acts to prepare for and respond to unexpected crises.

Urban green infrastructure provides cities with the capacity to withstand climate change-induced stresses. This role of green areas in providing climate adaptation services has been widely studied and demonstrated (e.g., Gill et al. 2007; Kazmierczak and Carter 2010). Urban forests and parks provide cooling benefits during hot summer (Norton et al. 2015), thus reducing the effect of urban heat island. Street tree canopies are suggested as a solution for shading pedestrian space, with broadleaf tree species being most effective in increasing thermal comfort (Leuzinger et al. 2010). Replacing hard paving with permeable and vegetated surfaces is encouraged for decreasing surface runoff (Pamukcu et al. 2014). Private small gardens help homes against temperature extremes (Cameron et al. 2012). Green walls and roofs are particularly beneficial for buildings with high solar exposure because they provide potential energy savings by improving building insulation (Monteiro et al. 2017; Ran and Tang 2018).

GI could increase its role in mitigating climate change effects when designed and developed in coordination with open water. As climate events become more uncertain and unpredictable, the need to retain and utilize stormwater as well as to daylight rivers, becomes increasingly important. In this situation, urban lakes and ponds can act as water storage and retention areas, and streams can aid the water flow of extreme rainy events. Urban water management systems can be particularly efficient if developed based on a systems approach which accounts for past hydrological structures (Deak and Bucht 2011; Ioja et al. 2018). Furthermore, open water surfaces can influence microclimate.

How can green infrastructure increase urban pandemic resilience?

In contrast to the well documented relationship between GI and urban climate resilience, research on the role of GI in addressing the challenges induced by the COVID-19 pandemic (and other similar events in the near future) is just emerging (Azevedo et al. 2020). However, studies conducted during the ongoing pandemic have shown just how important urban nature is for the physical and mental health and wellbeing of urban residents. Thus, we argue that GI can contribute to the social resilience of cities, by acting as refuge for urban residents during periods with high levels of stress. Lockdowns and restrictions have significantly altered mobility patterns, and in particular limited the access to outside-the-city recreation areas. Thus, urban green spaces have become an essential alternative for indoor sports activities. For example, the study by Venter et al. (2020) showed that pedestrian activity in Oslo increased in city parks, peri-urban forests, and protected areas during the pandemic. Samuelsson et al. (2020) argued that urban nature can help reduce stress momentarily and provide relaxation during long periods of social distancing and household confinement. Similar findings were reported by Ugolini et al. (2020).

Gavrilidis et al. (2020) showed that, when asked about aspects influencing their life quality, citizens place the overall environmental quality in the city and the existence of green spaces at the top of their preferences. Accessibility and usability of green areas are important aspects for improving the quality of life in urban settlements (Quatrini et al. 2019) for a variety of reasons related to wellbeing: sports or physical exercise (Hunter et al. 2015), observing nature especially when areas are rich in biodiversity (Carrus et al. 2015), and socializing activities (Zijlema et al. 2017).

The COVID-19 pandemic has caused double isolation, especially, for urban dwellers. In 2020, many countries were severely hit by the pandemic with huge numbers of positive cases and overwhelmed hospitals, forcing governments, especially during the first wave (e.g. Italy and Spain), to take drastic measures of social isolation (including quarantine and lockdown) and leading to behavioral changes of citizens. These included restrictions on outdoors activities, only allowing for essential duties or sports and some social distanced functions. While the containment measures contributed to lowering the virus outbreak and the number of positive cases, they strongly limited personal freedom and deprived people of their liberty to visit green spaces (Ugolini et al. 2020).

Ugolini et al. (2020) observed that people tended to visit green spaces nearby during the lockdown in

countries where movement was allowed only within a few hundred meters from home, but that city dwellers visited green areas at larger distances and on a regular basis in countries where the social isolation measures were less restrictive. Therefore, the pandemic and the measures set by governments influenced the choices of GI users. In this context, GI accessibility was crucial. Although urban parks seem the most preferred type of GI, people find alternatives such as neighborhood gardens, tree-lined streets, or even green areas outside the city as a way to do physical exercise, relax, or just take the dog out. Since essential activities are the only ones allowed during the pandemic, urban planning should increase the accessibility to green spaces by, for example, creating pocket parks within the urban fabric and green corridors for places of solace and respite.

How can strategic spatial planning contribute to designing GI to enhance urban resilience?

In order for GI to truly contribute to the resilience of cities, urban planning should address the challenges of the future. Thus, GI planning needs to anticipate the future and set long-term goals to meet these challenges. Strategic planning has been shown to be an appropriate tool for pursuing such endeavors because it is oriented towards developing long-term visions up to 50 years into the future (Albrechts et al. 2017). Moreover, strategic planning engages in collaborative practices, bringing together multiple actors and thus ensuring that their values and expectations are accounted for. Empirical evidence has shown that GI is already a key concept in strategic planning of urban regions due to its social, economic and ecological relevance (Gradinaru and Hersperger 2019).

Strategic planning conducted at urban region level can contribute to designing GIs that enhance resilience to climate change since it places environmental concerns among its goals along economic aspirations and focus on quality of life (Hersperger et al. 2019). Many strategic plans currently in place already address the challenges of climate change. For example, the strategic plans of Greater London (UK) and Sydney (Australia) include specific measures in this regard, such as reducing CO_2 emissions, developing green roofs, increasing urban canopy, reducing waste, and improving environmental performance.

In respect to the recent COVID-19 pandemic, the impact of the restrictions on the circulation of goods highlighted the need to develop food production areas within and near cities. Due to their accessibility, these areas can ensure the provision of food in times of crisis. By incorporating productive landscapes into GI, strategic planning could ensure resilience through the maintenance of agricultural areas and long-term food security (Barthel and Isendahl 2013) and recreation in cities. Previous research has shown that such approaches can be successful if stakeholders' preferences and expectations are accounted for, and if the multifunctionality of the network is enriched (Rolf et al. 2019). These ideas and approaches are completely in line with the principles of landscape sustainability science (Wu 2013; Opdam et al. 2018).

How should green infrastructure be expanded and improved?

Urbanization so far has been largely "a massive, unplanned experiment in landscape change" (Niemelä et al. 2011), and this situation must be rectified through sustainable and resilient urban planning and governance (Ahern 2013; Wu 2014). The implementation of GI in cities is normally a complex process involving a number of environmental, economic, and social factors.

Existing and potential users and their preferences

The continuous growth of the urban population is a stimulus for action towards enhancing livability in the urban environment, making it more pleasant, safe, and resilient to climate change, but also for creating a place where equity and equality (access to health, education, and other amenities) are respected and guaranteed for all citizens. It is well know how GI improves quality of life (Mat Nazir et al. 2014; Sanesi et al. 2017) and how GI should be available and accessible in all neighborhoods (WHO 2017), although improved GI in a poor neighborhood may trigger gentrification, making houses not affordable for all (Wolch et al. 2014; Anguelovski et al. 2018).

The characteristics of ecosystems that are part of the GI influence the behavior of their users, and the likelihood that a person has access to these ecosystems depends on individual behavior and preferences

(Schipperijn et al. 2010). Planning and design of GI thus should consider potential users and social groups living in cities, with the overall objective of minimizing social inequities in green space accessibility and maximizing the offer of GI to all social groups (La Rosa et al. 2018).

Most GI users are part of the local population, and they vary in terms of age classes and socio-economic status. Elderly people, families with children, teenagers and young people are important social groups that significantly enjoy the GI and benefit from easy access to it (Loukaitou-Sideris et al. 2016; Matisziw et al. 2016). They express different needs and preferences, especially when looking at the particular features of the components of GI (Ives et al. 2017), although recurring and cross-cutting preferences in green spaces can be identified (Henneberry et al. 2020). For example, the study by Onose et al. (2020) showed that the needs and preferences of elderly people can vary greatly from the ones of other social groups. GI should be designed to provide equitable access and diversified facilities to all users.

Availability of public land

The physical implementation of GI in cities requires availability and/or transformation of particular areas, mainly open space and non-urbanized areas. However, in densely built urban regions, available public areas are usually limited, and other potential public spaces for developing GI require acquisition by the public administration. Land acquisition is directly linked to the economic feasibility of the GI implementation, as direct public acquisitions of land are often economically unsustainable for local administration and can face resistance from private landowners (Bengston et al. 2004).

Acquisition of land may be more problematic for GI than other public services where the open spaces potentially for GI are located in private residential areas or belong to private landowners. Different property assets, therefore, put some constraints on the economic feasibility of new GI areas, especially when the public administrative bodies in charge of planning (i.e. municipalities) do not have the economic resources to purchase or acquire new GI areas (La Rosa and Privitera 2020). Operating on public-owned land implies less negotiation with landowners, whereas transformation on private land should be based on market conveniences. Accordingly, compensation and incentive tools, such as Carbon Offset Fund and Transfer of Development Rights (O'Rourke 2010; Falco and Chiodelli 2018) should be used to manage transformation of private land.

The potential of non-urbanized areas

Non-urbanized areas are areas free of urban development and with significant amounts of vegetation (natural, semi-natural or farmland) that can be integrated in GI (La Rosa and Privitera 2013). However, the potential of these areas should be verified by checking their suitability towards new elements of GI, as any planning decision about a change of land-use/land cover depends on the suitability of the land for a specific use. Comparing GI requirements with existing biophysical conditions (e.g., land-use, land cover, ecological fragmentation) would help to identify suitable sites for GI (Duc Uy and Nakagoshi 2008).

Characterizing existing non-urbanized areas and exploring their suitability to be part of GI can result in new spatial configurations of open spaces in urban or metropolitan contexts, encompassing a different range of ecosystem functions and services (from leisure to environmental protection, from crops production to social values) thus providing municipalities or other metropolitan public bodies (e.g. provinces or metropolitan areas) with a range of possibilities for the implementation of GI planning policy. This represents a relevant step forward for urban contexts where non-urbanized areas have historically suffered from high pressure from urban sprawl and have been treated as generic farmlands or undefined open spaces.

How can green infrastructure be incorporated into policy and planning?

Need for innovation in planning and policy framework

Cities around the world have different ways of creating and enhancing their GI, some of which may focus on cultural aspects, while others may aim to improve physical or ecological conditions (Gradinaru and Hersperger 2019). Nevertheless, to successfully incorporate GI in planning, there is a need to reform or

amend the current planning laws and policies at different administrative levels (national, regional, metropolitan, and municipal), so as to highlight the importance and urgency of GI for urban resilience and sustainability. Such reform may take different routes depending on sociopolitical and geographical contexts. Urban governance involves administrators and public decision-makers who manage, plan and find economic resources. The governance processes can broadly influence how spatial transformations can be implemented at different administrative levels, by specifying rules, limitations, constraints, taxes, fees, incentives, and compensation strategies. A reform that makes mandatory the inclusion of GI in spatial planning at different levels offers a possible path towards mainstreaming GI in current planning processes and increasing its use by planning authorities and practitioners.

Enhancing active involvement of stakeholders and the public

An increasing awareness about people's needs and rights (e.g. UN 2015) and the variety of ecosystem services provided by GI have led to re-thinking the way our cities are planned and managed, resulting in efforts and funding devoted to afforestation and other nature-based solutions (e.g. green roofs and walls). Building GI involves different sectors (e.g. urban planning, green management, sport, mobility, waste, etc.) and stakeholders (e.g. planners, managers, maintainers, users, etc.), and this web of actors should work in a more integrated way. At the municipal level, urban planning needs to incorporate hinterlands and suburbs that also share flows of people and resources with cities. The exchange of knowledge and information among municipal departments should be enhanced via digital technologies (Baud et al. 2016), and urban governance should be strengthened by encouraging participatory decision making and promoting shared vision and responsibilities among different groups of government agencies and local actors (Sandström et al. 2006). In particular, quality planning and management of public GI are essential. Professionally trained staff and properly equipped teams are necessary, and so are effective administrative and economic measures for quality and quantity of GI. At the same time, the involvement of local actors is also crucial; they are simultaneously the users, providers, and evaluators of GI (Ugolini et al. 2020).

At all levels, focus groups organized in person or through Apps and web-platforms (Rall et al. 2019), provide opportunities to find common interests, shared vision, and consensual priorities. While the involvement of academics and experts is important, a participatory approach that directly engages the stakeholders and the public is essential for assessing the cultural and social values of green spaces, empowering citizens, and increasing their sense of community and belonging. Collaborative and participatory approaches are vital to the science and practice of sustainability (Opdam et al. 2018; Cumming and Epstein 2020), and have become particularly prominent in landscape and urban planning during recent decades (e.g., Milovanovic et al. 2020; Opdam 2020).

Concluding remarks

There is much evidence that GI can increase urban resilience against climate change by reducing urban heat island effects, increasing thermal comfort, decreasing surface runoff, and insulating houses against temperature extremes, among many other benefits. In contrast, research on the benefits of GI in times of pandemics has just started. Recent studies in Europe have shown that GI acts as a refuge for urban residents during periods with high levels of stress, thus contributing to physical and mental health of urban dwellers and to social resilience of cities. However, accessibility of GI to urban residents differs across countries, as restrictions and lockdowns assume different requirements.

Building resilient cities requires anticipation of the impacts of ongoing challenges, preparing for mitigating their effects and designing response mechanisms. However, many cities around the world still follow traditional planning and management approaches to green spaces. In order for GI to be further incorporated into planning, new and innovative approaches are required. Innovation can be pursued in areas such as spatial/landscape governance, informed and effective involvement of stakeholders in decision processes; assessment of benefits of GI from a socio-ecological perspective, and access of all social groups to GI benefits. For innovation to take place, a combination of different approaches (e.g., traditional and

innovative, top-down and bottom-up) at different scales is needed, with those at the regional and metropolitan levels being more strategic and those at the local level being more operational. Through its focus on building long-term visions and its preoccupation with environmental concerns, strategic planning can contribute to designing GIs that enhance urban resilience. To ensure its quality, GI planning should provide equitable access and diversified facilities to all its current and potential users. Strategies for expanding the existing GI can make use of currently non-urbanized areas.

Cross-sectoral cooperation, transdisciplinary methods, and holistic approaches are needed to enhance the broad spectrum of benefits of GI to address existing urban environmental, social, and economic problems, including health issues. To this end, all the actors involved (policy makers, citizens as users or providers, academics and others) need to find a common language and mechanism to efficiently work together. Policy-makers need to think across different policy areas and sectors, and actively engage different stakeholders and local communities in decision-making processes. Cooperation can occur at different levels, from the neighborhood to the city, the metropolitan region, and beyond. In addition, public awareness and education of GI are essential, and we all need to understand that green spaces are integral parts of the urban landscape, and vital to urban resilience and sustainability.

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Compliance with ethical standards

Conflict of interest There are no conflicts of interests.

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